A STUDY ON EFFECT OF FIBER PARAMETERS ON MECHANICAL BEHAVIOUR OF NATURAL FIBER BASED POLYMER COMPOSITES

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF

BACHELOR OF TECHNOLOGY

IN

MECHANICAL ENGINEERING

BY

SAURAV SAHA

(ROLL: 107ME043)

DEPARTMENT OF MECHANICAL ENGINEERING
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CERTIFICATE

This is to certify that the thesis entitled ***"A Study on Effect of Fiber Parameters on Mechanical Behaviour of Natural Fiber Based Polymer Composites"*** submitted by ***Saurav Saha (Roll: 107ME043)*** in partial fulfillment of the requirements for the award of ***Bachelor of Technology*** in the department of Mechanical Engineering, National Institute of Technology, Rourkela is an authentic work carried out under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to elsewhere for the award of any degree.

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A C K N O W L E D G E M E N T

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ABSTRACT

Fiber reinforced polymer composites have many applications as a class of structural materials because of the case of fabrication, relatively low cost of production & superior cost as compared to polymer resins. The fiber which serves as a reinforcement in reinforced plastics may be synthetic or natural. Although the synthetic fibers such as glass, carbon, possess high specific strength, their fields of applications are limited because of their inherent higher cost of production. In this connection, an investigation has been carried out to make use of bamboo fiber which is a natural fiber abundantly available in India. Natural fibers are not only strong & light weight but also relatively very cheap. The objective of the present work is to study the effect of fiber loading and fiber length on mechanical behavior of bamboo fiber reinforced epoxy composites. Finally, the surface morphology of the composites of fractured surfaces has made using SEM study.

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CHAPTER 1
INTRODUCTION

1.1 Background

Now-a-day, the interest in composite materials is increasing rapidly both in terms of their research and applications. The composite materials have advantage over other conventional materials due to their higher specific properties such as tensile, impact and flexural strengths, stiffness and fatigue characteristics, which enable structural design to be more versatile. Due to their many advantages they are widely used in the aerospace industry, in a large number of commercial mechanical engineering applications, such as machine components; internal combustion engines; automobiles; thermal control and electronic packaging; railway coaches and aircraft structures; mechanical components such as drive shafts, tanks, brakes, pressure vessels and flywheels; process industries equipment requiring resistance to high-temperature corrosion, oxidation, and wear; dimensionally stable components; sports and leisure equipment; marine structures; and biomedical devices [1].

By definition *"A composite material is considered to be one that contains two or more distinct constituents with significantly different macroscopic behavior and a distinct interface between each constituent. It has characteristics that are not depicted by any of the components in isolation"* [2].

Composites are made up of individual materials referred to as constituent materials. The constituents of a composite are generally arranged so that one or more discontinuous phases are embedded in a continuous phase. The discontinuous phase is termed the reinforcement and the continuous phase is the matrix. The matrix phase generally comprises the bulk part of a composite. The matrix material surrounds and supports the reinforcement materials by maintaining their relative positions. The reinforcements impart their special mechanical and physical properties to enhance the matrix properties. A synergism produces material properties unavailable from the individual constituent materials, while the wide variety of matrix and strengthening materials allows the designer of the product or structure to choose an optimum combination. All of the different fibers used in composites have different properties and so affect the properties of the composite in different ways.

Composite materials can be classified into three categories depending on the type of matrix materials used such as metal matrix composites, polymer matrix composites and ceramic matrix composites. Each type of composite material is suitable for different applications. Among them, polymer matrix composites are the composites consisting of polymer as matrix material. These composites are characterized by the various properties such as high stiffness, high tensile strength, high fracture toughness, good corrosion and abrasion resistance, low cost etc. There are two major classes of polymers used as matrix materials such as thermoplastics and thermosets. Thermoplastics (nylon, polypropylene, acrylics etc.), can be repeatedly softened and re-formed by application of heat. However, thermosets (phenolic, epoxies etc.) on the other hand, are materials that undergo a curing process during part fabrication, after which they are rigid and cannot be re-formed. Among them epoxy is the most widely used matrix due to it advantages like good adhesion to other materials, good mechanical properties, good electrical insulating properties, good chemical and environmental resistance etc. Generally, the reinforcing material for polymer matrix composites include synthetic fibers such as glass fiber, kevlar fiber , carbon fiber etc. or natural/cellulose fibers such as cotton, jute, kenaf, bamboo fiber etc.

Recently, fiber reinforced polymer matrix composites have been widely used in various applications such as aerospace, automotive, marine etc. due to their high specific stiffness and strength [3]. These materials also provide high durability, lightweight and design flexibility, which make them attractive materials in these applications. Fiber reinforced polymer matrix composites can be simply described as multi-constituent materials that consist of reinforcing fibres embedded in a rigid polymer matrix. The properties of these composites are significantly related to the properties of composite constituents, i.e.; matrix, fiber and the interface between them. The fibres used in fiber reinforced polymer composites can be in the form of small particles, whiskers or continuous filaments. Properties of fiber reinforced polymer composites are determined by many factors such as properties of the fibers, fiber length, concentration of the fibers, orientation of the fibers, fiber-matrix interface strength, properties of the matrix etc. There are many factors to be considered when designing with composite materials. A crucial parameter for the design with composites is the fibre content, as it controls the mechanical and thermo-mechanical responses. The strength and stiffness of a composite can increase to a point with iincreasing the volume content of reinforcements. However, if the volume content of reinforcements is too high there will not be enough matrixes to keep them separate, and they can become tangled. Similarly, the fiber length is a very important parameter which affects the various properties of composite material. Therefore, in order to obtain the favoured material properties for a particular application, it is important to know how the material performance changes with the fibre content and fiber length under given loading conditions.

With the growing global energy crisis and ecological risks, natural fibers reinforced polymer composites have attracted more research interests due to their potential of serving as alternative for artificial fiber composites [4-6]. Accordingly, extensive studies on preparation and properties of thermoplastic and thermosetting composites filled with the natural fibers such as cotton, bamboo, sisal, coir, jute, hemp, flax, pineapple leaves, etc., were carried out. Compared with synthetic fibers such as glass fibers or carbon fibers, natural fibers have many advantages like high specific mechanical performance, renewable, low cost, lightweight, environmental friendly etc.

The term 'Natural Fibers' covers a broad range of animal, vegetable and mineral fibers. These fibers often contribute to the structural performance of the plant and when used in plastic composites can provide significant reinforcement. Natural fibers therefore can be divided into following categories depending up on their origin:-

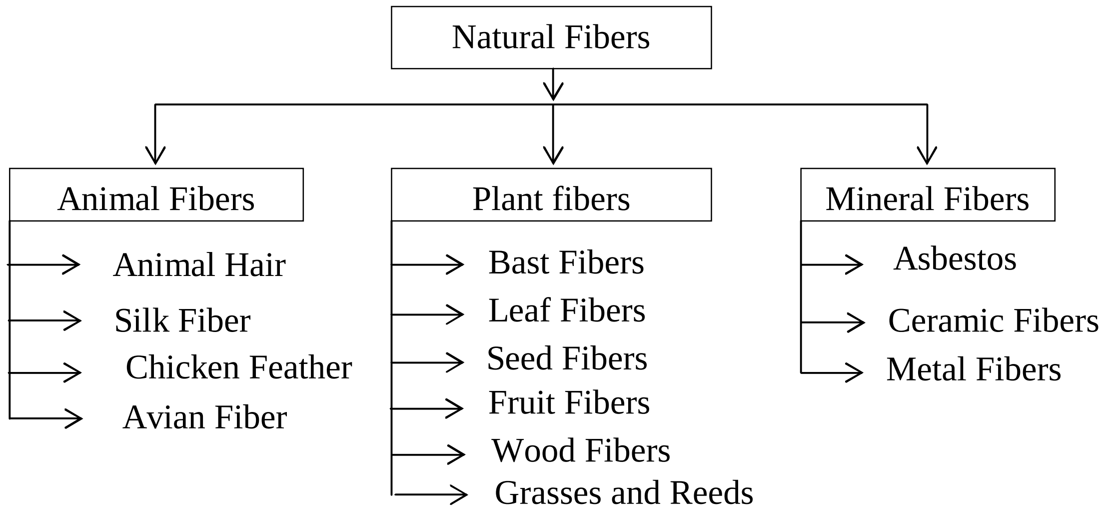

Figure 1.1 Classification of natural fibers

Natural fibers are complex, three dimensional, composed of cellulose, hemicellulose, pectin & lignin. These hydroxyl ion containing polymers are distributed throughout the fiber wall. Natural fibers can be considered as consisting of mainly cellulose fibrils (fibers) embedded in lignin matrix (resin). They also contain lesser amounts of additional extraneous components including low molecular wt. organic compounds (extractives) & inorganic matter (ash). Though often small in quantity, extractives can have large influences on properties such as color, odor and decay resistance. The composition of few natural fibers is given in Table. Natural fibers are added to plastics or polymers composites to improve mechanical performance such as stiffness & strength without increasing the density or cost too much. They are lighter than inorganic reinforcements which can lead to benefits such as fuel savings when their composites are used in transportation applications.

Table 1.1 Composition of few Natural Fibers [7, 8]

Natural Fiber	Cellulose (%)	Lignin (%)	Pentosans (%)	Ash (%)
Coir	43	45	-	-
Banana	65	5	-	-
Sisal	47-62	7-9	21-24	0.6-1
Jute	41-48	21-24	18-22	0.8
Bamboo	26-43	21-31	15-26	1.7-5
Kenaf	44-57	15-19	22-23	2-5
Cotton	85-90	0.7-1.6	1.3	0.8-2
Wood	40-45	26-34	7-14	<1

A great deal of research has been made on various natural fibers. Among them, bamboo is a natural fiber abundantly found in diverse climates, from cold mountains to hot tropical regions. They occur across East Asia, Northern Australia, and west to India and the Himalayas. They also occur in sub-Saharan Africa and in the Americas from the Mid-Atlantic United States south to Argentina and Chile. Bamboo is one material, which will have a tremendous economic advantage, as it reaches its full growth in just a few months and reaches its maximum mechanical resistance in just few years. There are more than 70 genera divided into about 1,450 species Bamboo is a composite material, consisting of long and parallel cellulose fibers embedded in a ligneous matrix. The bamboo column consists of many vascular bundles and xylem. A vascular bundle includes four sheaths of fibers, two vessels and some sieve tubes. Xylem surrounds each vascular bundle. The sheath consists of many single fibers whose diameter is 10-20 mm each in average [9]. The chemical constituents of bamboo are primary cellulose, hemi-cellulose and lignin. All lingo cellulosic based natural fibers consist of cellulose micro fibrils in an amorphous matrix of lignin and hemi-cellulose. The bamboo is consisting of 60% cellulose and a considerably high percentage of lignin (about 32%). The average diameters of the bamboo fibers are between 10 and 20 μm and average length is about 2 mm. The hardness of the bamboo column mainly depends on the number of fiber bundle and the manner of their scattering. The percentage of fibers decreases from the bottom to the top of the column [10]. The mechanical properties of different natural fibers such as sisal, Vakka, banana, bamboo are compared & it is found that the bamboo fibers have much higher tensile and flexural properties than other fibers [11]. Bamboo fibers have emerged as a renewable and cheaper substitute for synthetic fibers such as glass and carbon, which are used as reinforcement in making structural components. They have high specific properties such as stiffness, impact resistance, flexibility, and modulus and are comparable to those of glass fiber. Therefore, bamboo fibers are often called ‘natural glass fiber’. Several forms of bamboo can be used for reinforcement, such as the whole bamboo, sections, strips, and fibers. These various forms of bamboo have been used in applications such as low rise construction to resist earthquake and wind loads, bamboo mat composite in combination with wood for beams, and shear wall in low-rise construction. In addition, bamboo fibers can be used as reinforcement with various thermoplastic and thermoset polymers. However various properties of bamboo are greatly influenced by its chemical composition. The various species of bamboo with the chemical composition of bamboo leaves are given in Table 1.2.

The potential of bamboo has already explored in terms of various application, however their use in polymer matrix composites has very rare. To this end, the present research work is undertaken to study the processing, characterization of short bamboo fibre reinforced epoxy composites. Attempts have also been made to explore the possible use of a natural fiber for making value added product. The specific objectives of this work are clearly outlined in the next chapter.

Table 1.2 Average chemical composition (g kg-1) dry matter [DM]) of Bamboo leaves (n = 3) [12]

Species	OM	CP	EE	CHO	NDF	ADF	ADL	HC	C	Ash	AIA
Sasa auricoma	852	185	32	635	724	434	75	289	359	148	105
Bambusa nutans	882	182	25	675	785	439	73	346	366	118	82
Bambusa bambos	856	184	27	645	784	443	69	341	374	144	102
Phyllostachys aurea	841	180	34	627	742	457	79	285	378	159	108
Bambusa tulda	868	146	20	702	783	466	84	317	382	132	94
Dendrocalamus asper	847	176	36	635	762	469	59	293	410	15 3	98
Bambusa ventricosa	844	184	17	643	779	521	94	258	427	156	107
Dendrocalamus strictus	853	161	14	678	775	532	86	243	446	147	107
Melocanna baccifera	883	191	17	675	654	416	49	238	367	117	54
Dendrocalamus hookerii	914	179	42	693	742	457	72	285	385	86	44
Bambusa vulgaris	847	193	32	622	765	453	92	312	361	153	110

**P < 0.05; **P < 0.01; NS, P > 0.05. ADF, acid detergent fiber; ADL, acid detergent lignin; AIA, acid insoluble ash; C, cellulose; CHO, total carbohydrate; CP, crude protein; EE, ether extract; HC, hemicellulose; NDF, neutral detergent fiber; OM, organic matter.*

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CHAPTER 2

LITERATURE SURVEY

The purpose of this literature review is to provide background information on the issues to be considered in this thesis and to emphasize the relevance of the present study. The purpose of this chapter is also to provide a broad understanding of effect of fiber loading and fiber length on mechanical properties of fiber reinforced polymer composites.

In polymer composites, the reinforcing phase can either be fibrous or non-fibrous (particulates) in nature and if the fibers are derived from natural resources like plants or some other living species, they are called natural fibers. Most of the studies made on natural fiber composites reveal that their mechanical properties are strongly influenced by a number of parameters such as volume fraction of the fibers, fiber length, fiber aspect ratio, fiber-matrix adhesion, fiber orientation and stress transfer at the interface. Therefore, both the matrix and fiber properties are important in improving mechanical properties of the composites. A number of investigations have been made on various types of natural fibers to study the effect of these fiber parameters on the mechanical properties of composite materials. The mechanical properties of jute fabric-reinforced polyester composites has studied and found that they have better strengths than those of wood based composites [Gowda et al. [13]. Luo and Netravali [14] studied the tensile and flexural properties of green composites with different pineapple fiber content and compared them with the virgin resin. Van de Velde et al. [15] and Frederick et al. [16] studied the dynamic mechanical analysis of natural fibers like sisal, oil palm empty fruit bunch fiber, palm (pineapple leaf fiber) etc. in various matrices. A number of reports are available on investigations carried out on various aspects of types of natural fibers such as kenaf, hemp, flax, bamboo, and jute to study their effects on mechanical properties of composites.[17-20]. Shinichi et al. [21] have investigated the effects of the volume fraction and length of natural fibers like kenaf and bagasse on flexural properties of some biodegradable composites. Amash and Zugenmaier [22] reported on the effectiveness of cellulose fiber in improving the stiffness and reducing the damping in polypropylene-cellulose composites. Similarly, a study on pulp fiber reinforced thermoplastic composite exhibited that while the stiffness is increased by a factor of 5.2, the strength of the composite is increased by a factor of 2.3 relative to the virgin polymer [23]. Schneider and Karmaker [24] studied the composites using jute and kenaf fiber in polypropylene resin and reported that jute fiber provides better mechanical properties than kenaf fiber. Sapuan and Leenie [25] carried out tensile and flexural tests on natural fiber reinforced musaceae/epoxy composites. Cazaurang et al. [26] done a systematic study on the properties of henequen fiber and pointed out that these fibers have mechanical properties suitable for reinforcement in thermoplastic resins. Srivastav et al. [27] have studied the effect of different loading rate on mechanical behavior of jute/glass reinforced epoxy hybrid composites.

Several investigators have also reported on mechanical properties of natural fiber composites fabricated by different manufacturing techniques. Hepworth et al. [28] studied the hemp fiber reinforced epoxy composites, with a fiber volume fraction of 0.2, a tensile strength of 90 MPa and Young’s modulus of 8 GPa, by pinning-decortications and hand combing. The structural characteristics and mechanical properties of coir fiber reinforced polyester composites were evaluated and the effect of the molding pressure on the flexural strength of the composites was studied [29]. The effect of fiber volume fraction on Young’s modulus, maximum tensile strength and impact strength of untreated jute fibers in unsaturated polyester resin, made by a leaky mould technique is studied by Chawla and Bastos [30]. The mechanical properties of flax/polypropylene compounds, manufactured both with a batch kneading and an extrusion process is studied by Harriette et al. [31]. A great deal of work has also been reported by many investigators on the impact behavior of natural fiber reinforced composites. The fracture energies for sisal, banana, pineapple and coconut fiber reinforced polyester composites using Charpy impact tests is studied by Pavithran et al. [32]. They found that, except for the coconut fiber, increasing fiber toughness was accompanied by increasing fracture energy of the composites. The post-impact behavior of plain-woven jute/polyester composites subjected to low velocity impact was studied and found that the impact performance of these composites was poor by Santulli et al. [33]. Biswas et al. [34] studied the effect of fiber length on mechanical behavior of coir fiber reinforced epoxy composites.

Effect of fiber parameters on bamboo fiber reinforced composites has studied by few investigators. Xian et al. [35] studied the mechanical properties and microstructure of bamboo fiber reinforced epoxy composites. In their study, bamboo strips split longitudinally from internodal sections of a culm were pressed by rolling between a pair of steel cylinders and embedded in an epoxy matrix. Composites of three different types were fabricated such as composites consisting of three layers, five layers and seven layers, all consisting of unidirectional fibers. The tensile, compressive, flexural and inter-laminar shear properties were investigated on a macroscopic scale by means of an Instron 1195 universal testing machine. Wonga et al. [36] studied the effect of fiber length and fiber content on fracture behavior of short bamboo fiber reinforced polyester composites. Abhijit et al. [37] examined the effect of fiber diameter on different bamboo composites. In their study, conventional methods of compression molding technique and roller mill technique were explored for the mechanical separation. The effect of mass fraction of fiber and coupling agent on dynamic thermal mechanical properties of bamboo fiber/Polylactic Acid (PLA) composites were studied by the thermal dynamic mechanical analyzer [38]. Yongli et al. [39] investigated the effect of different fiber sizes and composition of fibers on the mechanical properties of bamboo composites. It has been observed from their study that, because interfacial compatibility between bamboo fiber and matrix was poor, the dynamic thermal mechanical properties of composites were bad when coupling agent was not added. With the increase of mass fraction of bamboo fiber, the dynamic thermal mechanical of properties became even worse. But when coupling agent was added up to 2% and mass fraction of bamboo fiber was 55%, the dynamic thermal mechanical properties of composites were improved significantly. The effect of fiber content on mechanical behavior of bamboo fiber reinforced epoxy composite was evaluated by Bahrom et al. [40]. The variation of the fiber volume fraction of the bamboo shell was determined for 3 samples each for 10 columns taken from the top, bottom and middle part. It has been observed from their study that, the unidirectional composite had a higher tensile strength and multidirectional composite had higher flexural strength. The tensile strength decreases with the increase in number of layers whereas flexural strength increases. This shows that the tensile strength of bamboo fiber composite depends on the degree of the orientation of the fiber & flexural strength on the number of layer or thickness of the composite. Yong and Yi-qiang. [41] evaluated the effect of fiber length on strength of bamboo fiber and mechanical properties of fiber reinforced green composites. Two types of composites were made by fabricating bamboo fibers with poly-vinyl alcohol and cornstarch based biodegradable resin. The result shows from their study that the tensile strength of fiber decreases with the increase of diameter. Tensile strength and elastic modulus of bamboo-poly-vinyl alcohol composites increases with an increase of pressure in composites at a fiber volume fractions of around 0.7, whereas for bamboo-cornstarch based biodegradable resin composites the tensile strength increases from 270 to 300 Mpa with the fiber volume fraction increasing from 0.5 to 0.7.

2. 1 The knowledge gap

An exhaustive literature review of the present study reveals that although the literature is rich in new developments in the composite materials technology, it lacks tremendously a consistent analysis of effect of fiber loading and fiber length on mechanical behavior of short bamboo fiber reinforced polymer composites.

2.2 Objectives of the present research work

The knowledge gap in the existing literature review has helped to set the objectives of this research work which are outlined as follows:

1. Fabrication of a new class of epoxy based composites reinforced with short bamboo fibers.
2. Evaluation of mechanical properties such as tensile strength, flexural strength, impact strength, and micro-hardness etc.
3. To study the influence of fiber loading and fiber length on mechanical behavior of short bamboo fiber reinforced epoxy composites.
4. To study the fracture surface morphology using SEM study.

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CHAPTER 3

MATERIALS AND METHODS

This chapter describes the details of processing of the composites and the experimental procedures followed for their characterization. The raw materials used in this research work are as follows:

1. Epoxy resin
2. Short bamboo fiber
3. Hardener

3.1 Preparation of composites

In this study, short bamboo fibers are taken as reinforcement which is collected from local sources. The epoxy resin and the hardener (HY951) are supplied by Ciba Geigy India Ltd. A stainless steel mould having dimensions of 210 × 210 × 40 mm^3 is used for composite fabrication. The short bamboo fibers are mixed with epoxy resin by the simple mechanical stirring. The composites are prepared in four different fiber loading and four different fiber lengths and the mixture is poured into various moulds conforming to the requirements of various testing conditions and characterization standards. Figure 3.1 shows short bamboo fiber and bamboo fiber reinforced epoxy composite and the detailed composition and designation of the composites are presented in Table 3.1. The cast of each composite is cured under a load of about 50 kg for 24 hours before it removed from the mould. Then this cast is post cured in the air for another 24 hours after removing out of the mould. Specimens of suitable dimension are cut using a diamond cutter for mechanical tests.

Figure 3.1 Short Bamboo Fiber and bamboo based composite.

Table 3.1 Designation of Composites

Composites	Compositions
C1	Epoxy + (0 wt.%) Bamboo Fiber (length 1.2 cm)
C2	Epoxy + (15 wt. %) Bamboo Fiber (length1.2 cm)
C3	Epoxy+ (30 wt%)Bamboo Fiber (length 1.2 cm)
C4	Epoxy + (45 wt. %) Bamboo Fiber (length 1.2 cm)
C5	Epoxy + (45 wt. %) Bamboo Fiber (length 1cm)
C6	Epoxy + (45 wt. %) Bamboo Fiber (length 1.5cm)
C7	Epoxy + (45 wt. %) Bamboo Fiber (length 2 cm)

3.2. Mechanical testing of composites

Micro-hardness measurement is done using a Leitz micro-hardness tester. A diamond indenter, in the form of a right pyramid with a square base and an angle 136^0 between opposite faces, is forced into the material under a load F. The two diagonals X and Y of the indentation left on the surface of the material after removal of the load are measured and their arithmetic mean L is calculated. In the present study, the load considered F = 24.54N and Vickers hardness number is calculated using the following equation.

$$H_V = 0.1889\frac{F}{L^2} \quad \text{and} \quad L = \frac{X+Y}{2}$$

Where F is the applied load (N), L is the diagonal of square impression (mm), X is the horizontal length (mm) and Y is the vertical length (mm).

The tension test is generally performed on flat specimens. The most commonly used specimen geometries are the dog-bone specimen and straight-sided specimen with end tabs. A uni-axial load is applied through the ends. The ASTM standard test recommends that the specimens with fibers parallel to the loading direction should be 11.5 mm wide. Length of the test section should be 100 mm. The test-piece used here was of dog-bone type and having dimensions according to the standards. The tension test was performed on all the three samples as per ASTM D3039-76 test standards.

A three point bend test is conducted for finding out flexural strength of composites using Instron 1195. A span of 30 mm was taken and cross head speed was maintained at 10 mm/min. The strength of a material in bending is expressed as the stress on the outermost fibers of a bent test specimen, at the instant of failure. In a conventional test, flexural strength expressed in MPa is equal to

$$\text{Flexural Strength} = 3PL / 2bd^2$$

Where P= applied central load (N)

L= test span of the sample (m)

b= width of the specimen (m)

d= thickness of specimen under test (m)

Low velocity instrumented impact tests are carried out on composite specimens. The tests are done as per ASTM D 256 using an impact tester. The pendulum impact testing machine ascertains the notch impact strength of the material by shattering the V-notched specimen with a pendulum hammer, measuring the spent energy, and relating it to the cross section of the specimen. The standard specimen for ASTM D 256 is 64 × 12.7 × 3.2 mm and the depth under the notch is 10.2 mm.

3.3 Scanning electron microscopy (SEM)

The surfaces of the composite specimens are examined directly by scanning electron microscope JEOL JSM-6480LV (Figure). The samples are washed, cleaned thoroughly, air-dried and are coated with 100 Å thick platinum in JEOL sputter ion coater and observed SEM at 20 kV. Similarly the composite samples are mounted on stubs with silver paste. To enhance the conductivity of the samples, a thin film of platinum is vacuum-evaporated onto them before the photomicrographs are taken.

Figure 3.3 SEM Set up

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CHAPTER 4

MECHANICAL CHRACTERISTICS OF COMPOSITES: RESULTS & DISCUSSION

This chapter presents the results of mechanical properties of short bamboo fiber reinforced composites. Also, the effect of fiber parameters such as fiber loading and length on mechanical behavior of short bamboo fiber reinforced epoxy composites is discussed here.

4.1 Mechanical characteristics of composites

The properties of the short bamboo fiber reinforced epoxy composites with different fiber loading and fiber length under this investigation are presented in Table 4.1 and Table 4.2 respectively. Table 4.1 shows the mechanical properties of composites with different fiber loading at a constant fiber length of 1.2cm. It is evident from the Table 4.1 that at 45wt% of fiber loading the composites show better mechanical properties as compared to others. Table 4.2 shows the mechanical properties of composites with different fiber length by taking a constant fiber loading of 45wt%.

Table 4.1 Mechanical properties of the composites with different fiber loading (For 1.2cm length)

Composites	Hardness (Hv)	Tensile strength (MPa)	Flexural strength (MPa)	Impact strength (J)
C1	32	4.62	16.41	0.2451
C2	38	7.59	25.70	0.3044
C3	45	9.86	31.27	1.0258
C4	46	10.48	19.93	1.3764

Table 4.2 Mechanical Properties of the composites with different fiber length

Composites	Hardness (Hv)	Tensile strength (Mpa)	Flexural strength (MPa)	Impact strength (J)
C5	45.7	9.80	17.93	1.3476
C4	46	10.48	19.93	1.3764
C6	47.5	11.56	21.67	1.4872
C7	46.5	15.45	22.32	1.5763

4.1.1 Effect of fiber loading on hardness of composites

Surface hardness of the composites is considered as one of the most important factors that govern the structural properties of the composites. Figure 4.1 shows the effect of fiber loading on hardness of composites under constant fiber length (1.2mm). The test results show that with the increase in fiber loading hardness (Hv) value of the short bamboo-epoxy composites is improved [Figure 4.1]. These values are compared with the reported micro-hardness values of glass-polyester composites [42]. Which clearly indicates that inclusion of bamboo fiber in the epoxy matrix body results in improved the hardness although this improvement is marginal.

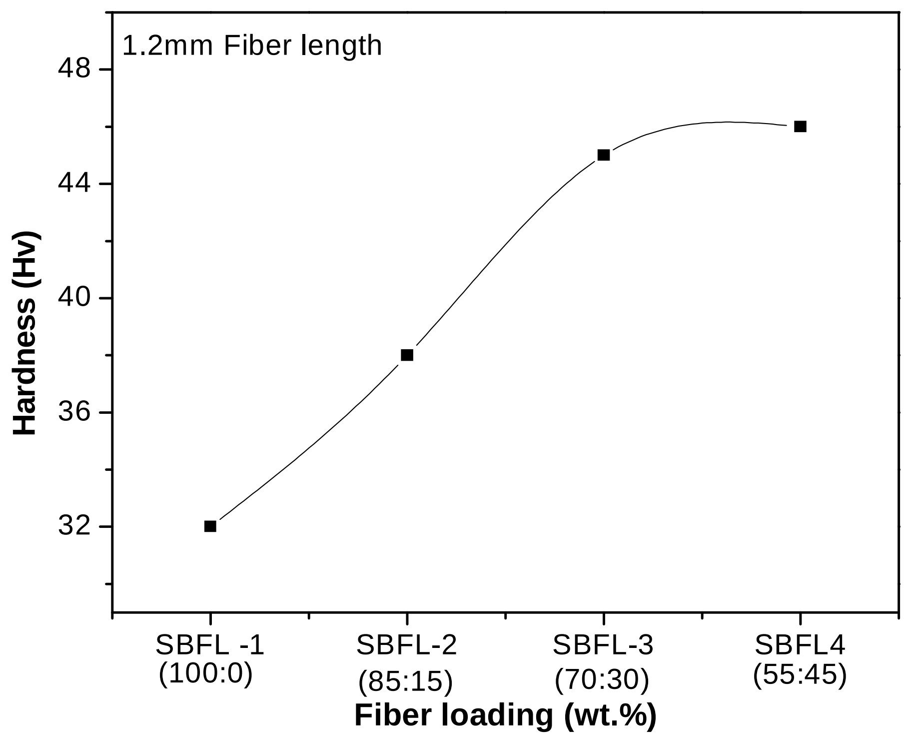


Figure 4.1 Effect of fiber loading on hardness of composites

4.1.2 Effect of fiber loading on tensile strength of composites

The effect of weight fraction of fibre in the composite on the tensile strength is shown in Figure 4.2. As the weight fraction of fibre increases in the composite the tensile strength of short bamboo fibre composite is 10.48MPa which is slightly higher than that of jowar composite, and is due to slightly lower density of bamboo composite compared to jowar composite. The tensile properties measured in the present work are well compared with various earlier investigators [43-48], though the method of extraction of bamboo fiber is different.

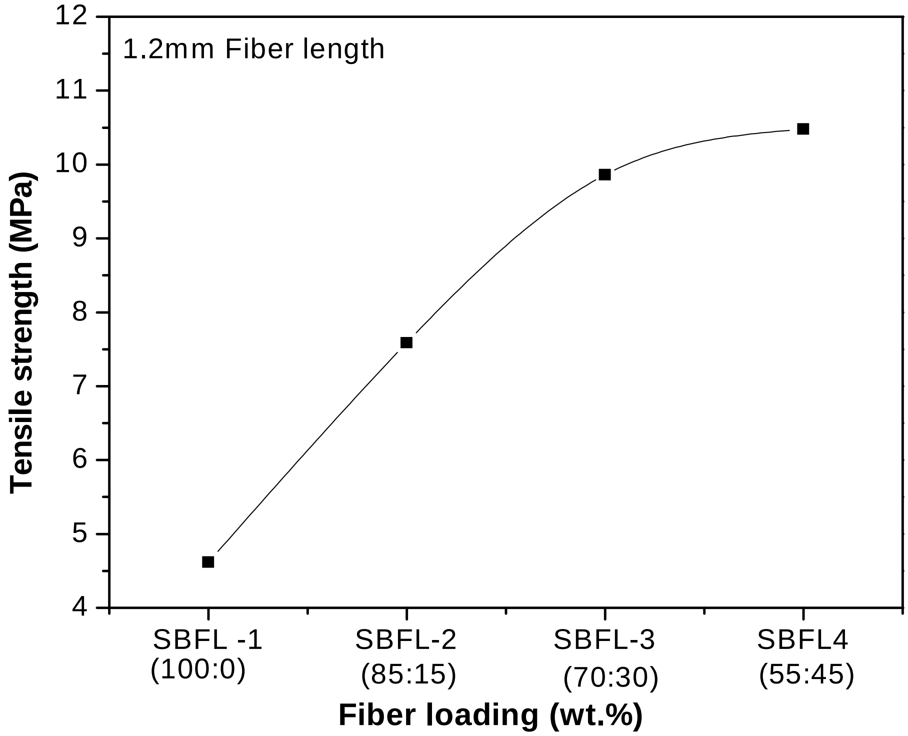


Figure 4.2 Effect of fiber loading on tensile strength of composites

4.1.3 Effect of fiber loading on flexural strength of composites

Figure shows the effect of fiber loading on flexural strength of composites. From the figure it is clear that the flexural strength of composites significantly increases with the increase of fiber loading up to 30wt%, however further increase in fiber loading flexural strength decreases.

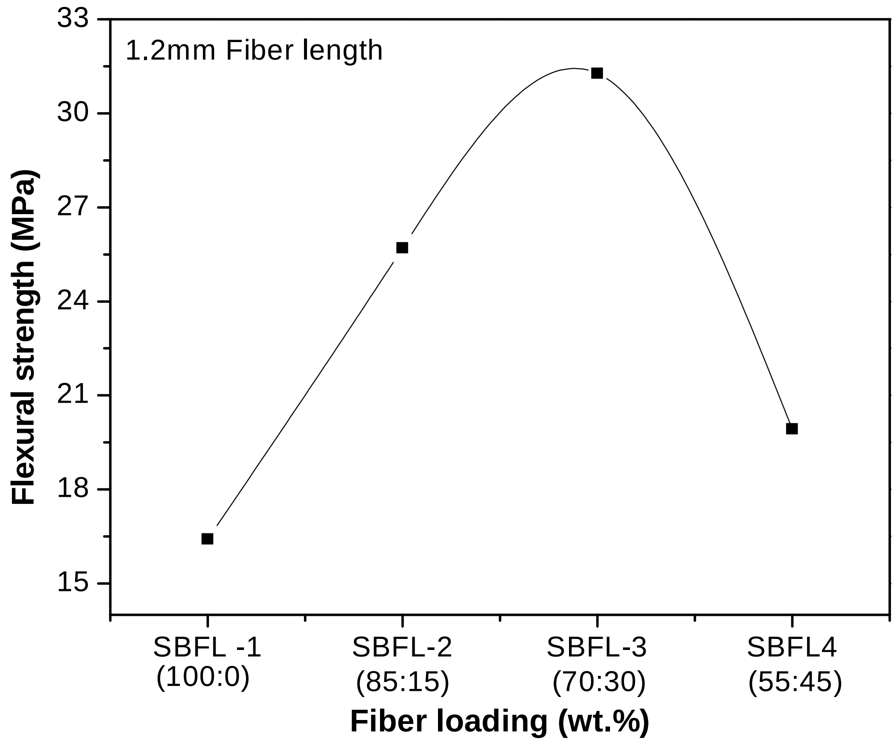


Figure 4.3 Effect of fiber loading on flexural strength of composites

Adversely, as shown in Figure 4.3, the flexural strength increased by the increase of fiber loading up to 30wt%. For instance, flexural strength of bamboo-epoxy composite is increased from 16.41MPa to 31.27MPa i.e. up to 30wt% and then decreased from 31.27MPa to 19.93MPa i.e. up to 50wt% respectively (Figure 4.3). It is also observed from Figure 4.3 that a linearly increasing trend up to a certain value of fiber loading (30wt%) and suddenly drops due to failure of specimens and the arrest points correspond to breakage and pull out of individual fibres from the resin matrix. This is due to higher flexural stiffness of bamboo composite and the improved adhesion between the matrix and the fibre. The effect of weight fraction of fibre on mean flexural strength for other fibre reinforced composites in comparison to bamboo composites are more. According to Ismail et al. [49] and Yao and Li [50], this decrease is attributed to the inability of the fiber, irregularly shaped, to support stresses transferred from the polymer matrix and poor interfacial bonding generates partially spaces between fiber and matrix material and as a result generates weak structure. As flexural strength is one of the important mechanical properties of the composites. For a composite to be used as the structural application it must possess higher flexural strength.

4.1.4 Effect of fiber loading on impact strength of composites

Since polymer composites reinforced with natural fibers are mainly used in structural applications, their impact resistance is also one of the important concerns. Regardless of types of modifiers, the improvement in impact toughness with respect to the short bamboo fiber reinforced epoxy composite is seen in Figure 4.4. The impact strength of the composites first it increases at a small rate i.e up to 15wt% and on further increase in fiber loading the strength increases drastically. The decrease in impact strength or smaller variation in strength may be due to induce micro-spaces between the fiber and matrix polymer, and as a result causes numerous micro-cracks when impact occurs, which induce crack propagation easily and decrease the impact strength of the composites [51,52]. This result proves that kenaf has higher properties [53] and can be less weakening agent than rice husk [54].

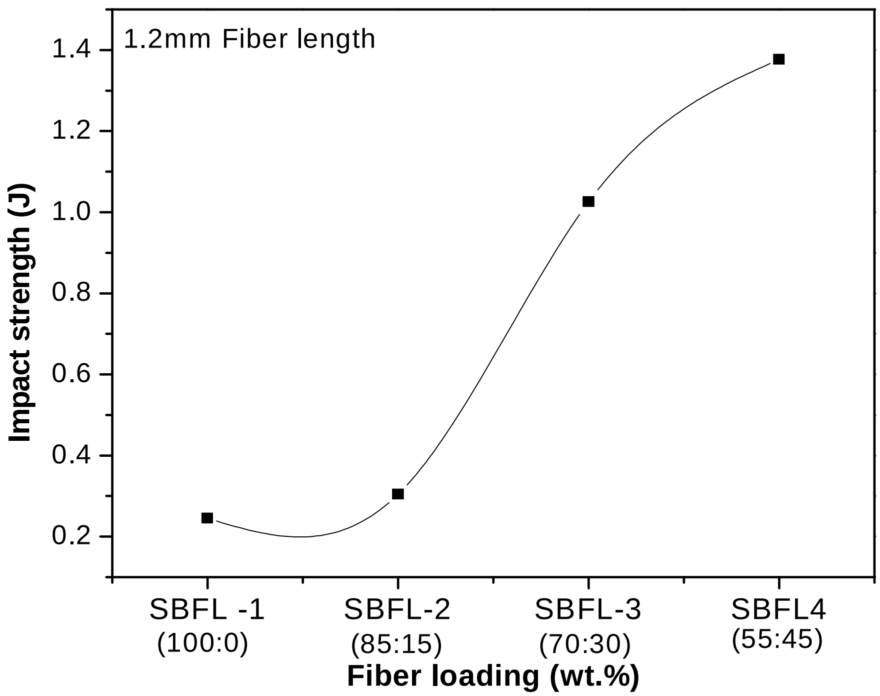


Figure 4.4 Effect of fiber loading on impact strength of composites

4.1.5 Effect of fiber length on hardness of composites

The Rockwell-hardness test results are presented in Figure 4.5 as a function of bamboo fiber (wt %). Hardness is a function of the relative fiber loading and modulus of the composites [55]. Fibers that increase the moduli of composites should also increase the hardness of thermoplastic composites. As the relative fraction of bamboo fiber in the composite increase, the hardness of composite increase as well. On the other hand, as the length of bamboo fiber increases, the hardness index would increase. Figure 4.5 shows the effect of fiber length on hardness of composites. It is evident from the figure that the hardness of composites significantly increases with the increase of fiber length up to 1.5cm, however, on further increase in fiber length up to 2 cm the hardness decreases gradually. The decrease in hardness may be fiber weight fraction and epoxy resin content is not sufficient to bind each other. Therefore, automatically the void content in the composites increases with the increase in fiber loading.

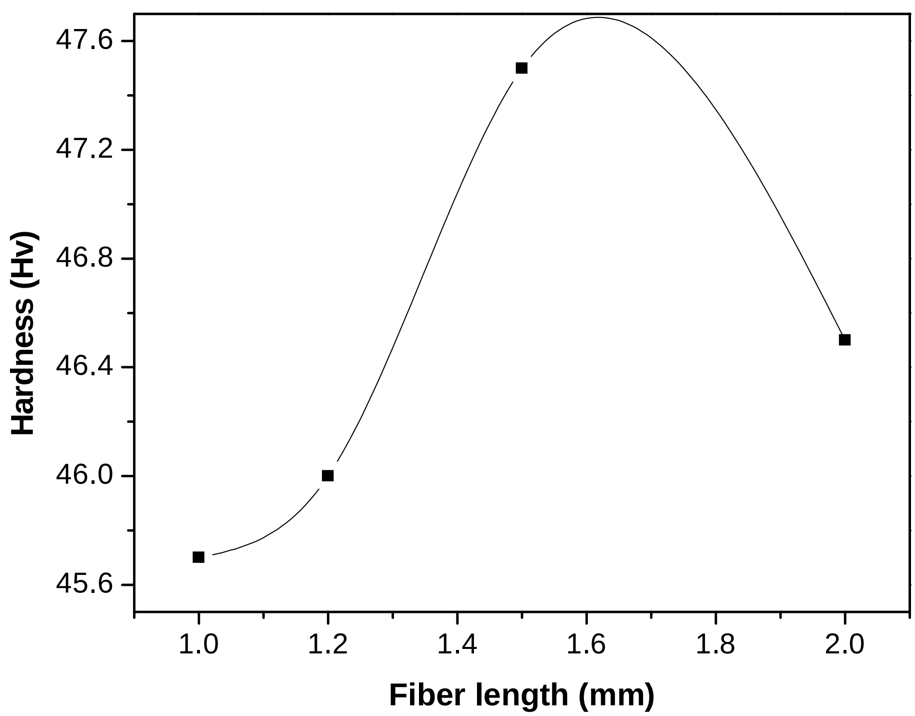


Figure 4.5 Effect of fiber length on hardness of composites

4.1.6 Effect of fiber length on tensile strength of composites

Figure 4.6 depicts the effects of fibre lengths fraction on tensile strength of the composites at constant fibre weight fraction. From the figure, it is observed that at fibre length of 2cm, the composite shows higher tensile strength than that of 1cm fiber length with similar weight fraction (45wt%). As for fibre length of 1.2cm, the tensile strength is slightly higher than the 1cm fiber length composite at 45wt.% fiber loading. When the fibre length is increased to 2cm, the yield strength is found to be consistently higher than 1cm and 1.5cm fiber length. Further improvement could be achieved by reinforcing the matrix at critical fibre length and/or improving the fibre/matrix bonding [56]. Generally, the results reveal that the load transfer is improved with increment in fibre length. Similar results were reported with sisal [57] and pineapple [58] fibres, where the tensile properties were improved with fibre length up to 6 mm. Besides, Brahmakumar et al. [59] also reported that tensile properties of the coconut fibre composites increased with fibre length up to 20 mm.

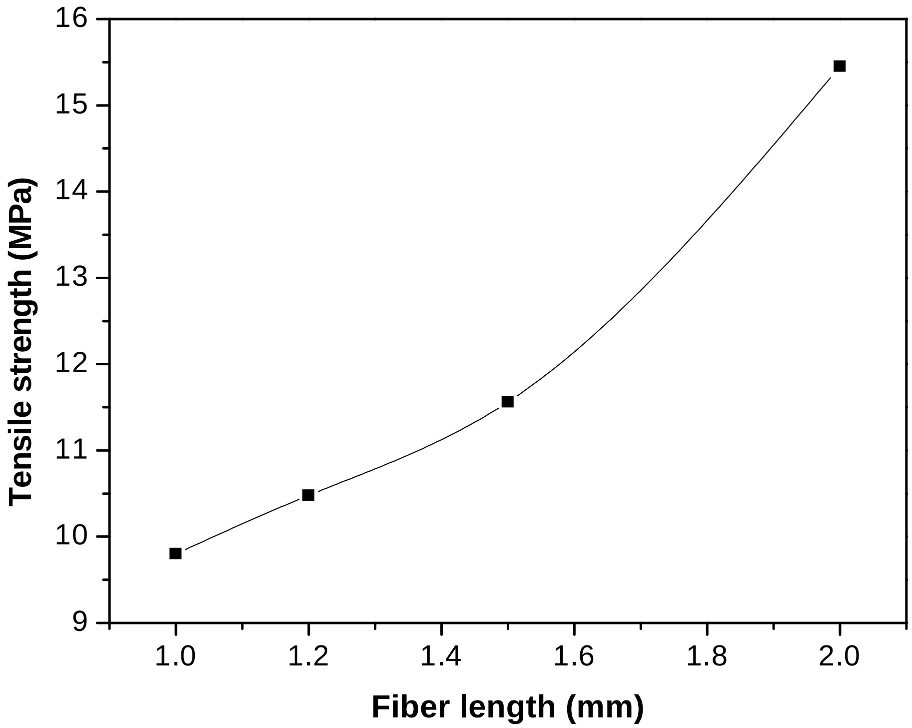


Figure 4.6 Effect of fiber length on tensile strength of composites

4.8. Effect of fiber length on flexural strength of composites

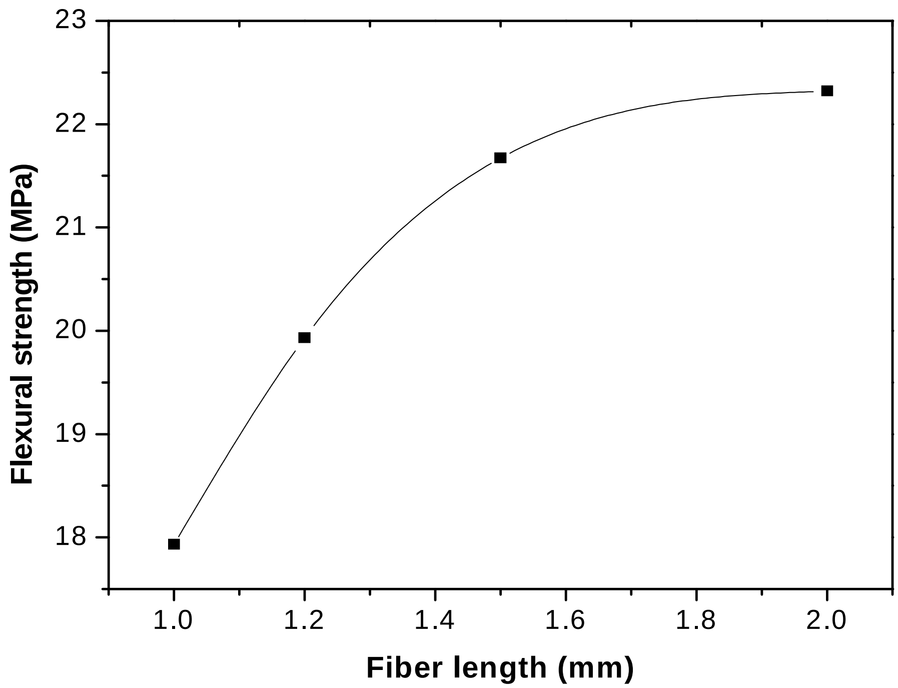


Figure 4.7 Effect of fiber length on flexural strength of composites

Although there are not many test carried out for the flexural properties of composites, this properties is important to study the fracture behavior. Regarding PALF reinforced polyester, Uma Devi et al.[60] pointed that the addition of fibre made the composite more ductile. In this work, the flexural strength values of the bamboo epoxy composites are increased with the increase in fiber length under constant fiber loading i.e 45wt%. However, in the previous case with increase in fiber loading the flexural strength increases up to 30wt% and then decreases up to 45wt% fiber loading but keeping the fiber length constant (1.2mm) as shown in Figure 4.3. To explain this, the author pointed that higher fibre loading encouraged fibre-to-fibre interaction and the fibre were not well dispersed within the resin latex. For this research, the best result was obtained at fibre loading of 30 wt % when fiber length is 1.2cm. But with the increase in fiber length the maximum flexural increases as shown in Figure 4.7. On the other hand the increase in strength may also depend on the fiber and matrix mixing time. The orientated composite exhibits higher tensile properties describes that as rotor speed is higher, the tensile properties increased. However there is a level off at the peek point of 60 rpm. The increased rotor speed to 80 rpm shows reduction in strength occurs due to the fibre breakage at higher rotor speed.

4.1.8 Effect of fiber length on impact strength of composites

Figure 4.8 shows the effect of fiber length on impact strength of composites. It is evident from the figure that the impact strength of composites significantly increases with the increase of fiber length. Typically, most people accepted that the toughness of a fibre composite is depending on the fibre stress-strain behavior. For the fact that bamboo fibers are comparatively strong fibres with high failure strain, it imparts a high work of fracture to the composite. Fibre pullout and interface fracture were the major contributions toward the high toughness of these composites. It is known that the enhanced toughness of polymer–fiber composites containing elastomers or rubbers can be realized by toughening either matrix or interfaces around fibers. Toughening of matrix tends to reduce ultimate strength of composites due to inferior bulk modulus of added elastomers, while strengths of final composites in the toughening of interfaces might be either decreased or increased, depending on interface nature.

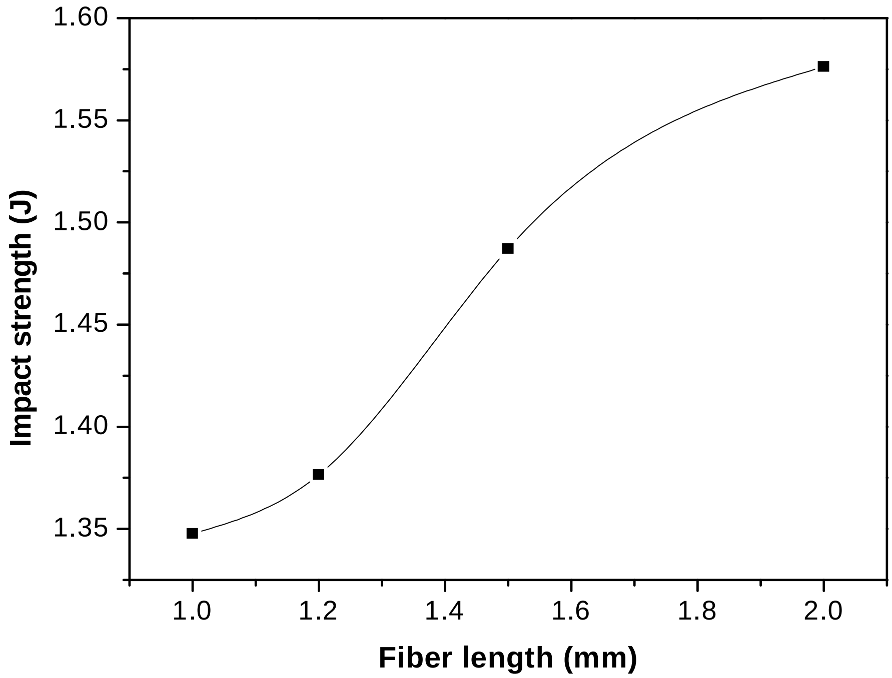
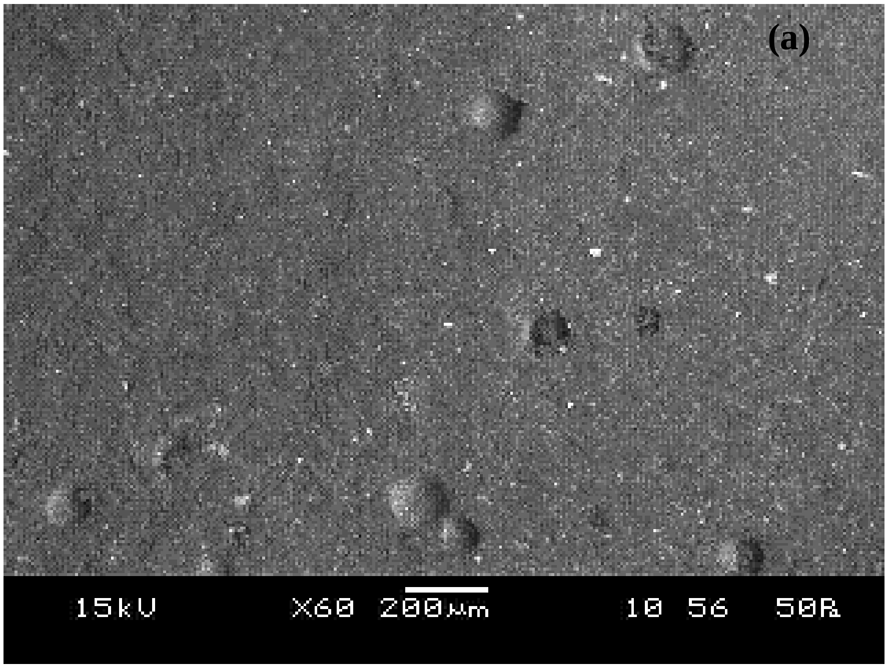
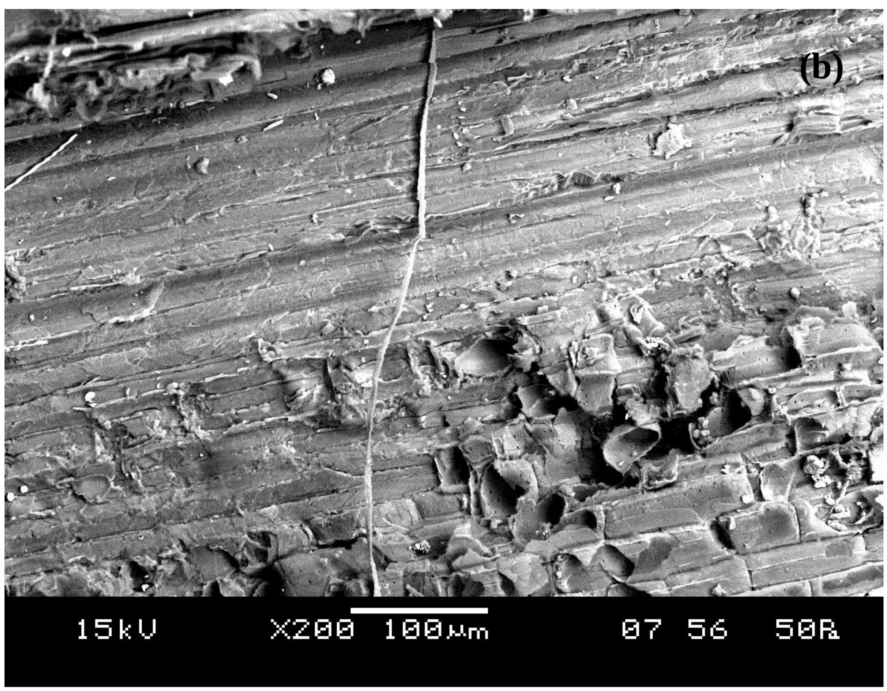


Figure 4.8 Effect of fiber length on impact strength of composites

4.2 Surface morphology of the composites

The fracture surfaces study of short bamboo fiber reinforced epoxy composite after the tensile test has been shown in Figure 4.9. From the Figure it can be seen that the fibers are detached from the resin surface due to poor interfacial bonding. The surface of the fiber is not smooth indicating that the compatibility between fibers and epoxy matrices is poor. However this compatibility can be improve when fiber will be treated by chemical treatment methods.


(a)
15kV X60 200µm 10 56 50R


(b)
15kV X200 100µm 07 56 50R

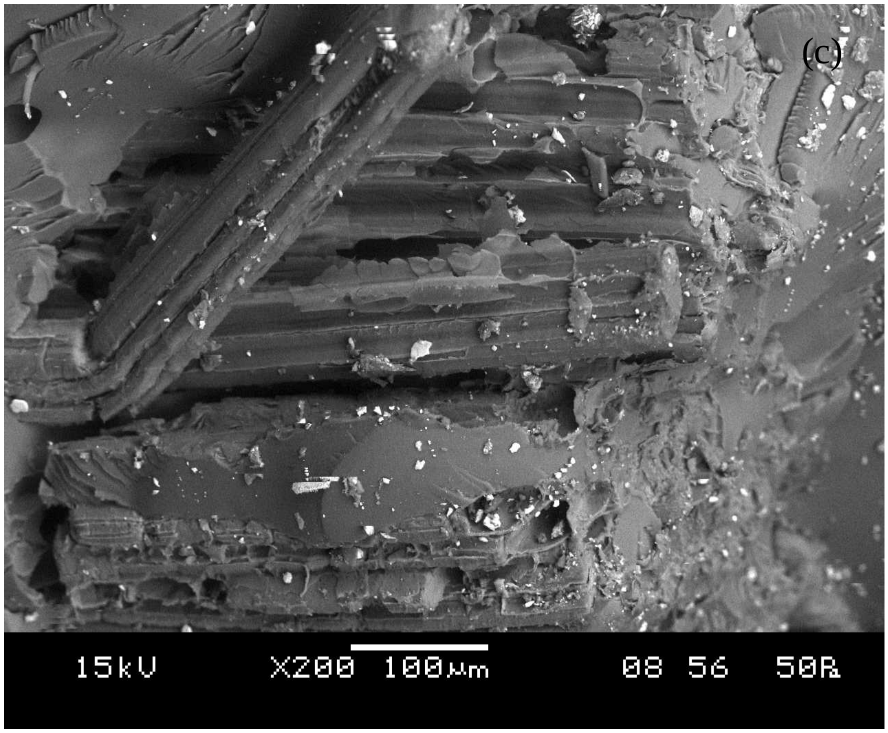


Figure 4.9 Scanning electron micrographs of bamboo fiber reinforced epoxy composite specimens after tensile testing.

Figure 4.9(a) shows the fiber reinforced epoxy composite without tensile test sample. It is observed from the figure that the surface looks very smooth and lesser void content as shown on the upper surface of the composite sample. On applying tensile load on the 45wt% of bamboo fiber reinforced epoxy composite the fractured surface of composite shows breaking of matrix material under initial loading condition (Figure 4.9(b)). This is because without fibres to retard the crack growth upon external loading, the crack would propagate in an unstable manner. Besides, it is also observed that there is matrix plastic deformation near the crack tip, which contributes to plastic zone generation in the material. However, with the increase in tensile load up to yield point relatively long extruding fibres can be observed, which is depicted by fibre pullout as shown in Figure 4.9(c). It is an indication of crack deflection, where the crack path is changed by the fibre and directed along the fibre surface. This leads to fibre debonding, which is an indication of matrix separation around the fibres as crack front intersects the fibre/matrix interface. Subsequently, it causes fibre pull-out. In this case, energy is dissipated by shear. Furthermore, fibre end damage and fibre split are observed, when the fibre length increases up to 2cm, highest fracture toughness is obtained at higher fibre weight fraction. This further confirms that longer fibre could dissipate the energy more effectively. Figure 4.9(c) describes comparatively severe fibre damage on those long extruding fibres. At higher fibre loading, there are more fibre surfaces in contributing to energy dissipation, thus further improving the fracture resistance. It has also been reported that long continuous sisal composites are consistently having higher fracture toughness than short sisal composites at similar fibre volume fraction [61]. Fu et al. [62] also reported that increasing fibre length improved fracture resistance due to better energy dissipation.

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CHAPTER 5
CONCLUSIONS

The experimental investigation on the effect of fiber loading and fiber length on mechanical behavior of short bamboo fiber reinforced epoxy composites leads to the following conclusions obtained from this study are as follows:

1. The successful fabrications of a new class of epoxy based composites reinforced with short bamboo fibers have been done.
2. It has been noticed that the mechanical properties of the composites such as hardness, tensile strength, flexural strength and impact strength etc. of the composites are also greatly influenced by the fiber loading and fiber length.
3. The present investigation revealed that 45wt% fiber loading shows superior hardness, tensile strength and impact strength. Whereas, for tensile strength show better in 30wt% of fiber loading. As far as effect of to fiber length on mechanical properties of composites is concerned, fiber length of 1.5cm shows superior hardness, however tensile strength, flexural strength and impact strength shows better in fiber length of 2cm.
4. The fracture surfaces study of short bamboo fiber reinforced epoxy composite after the tensile test has been done. From this study it has been concluded that the poor interfacial bonding is responsible for low mechanical properties.

5. 1 Scope for future work

There is a very wide scope for future scholars to explore this area of research. This work can be further extended to study other aspects of such composites like use of potential fillers for development of hybrid composites and evaluation of their mechanical behavior and the resulting experimental findings can be similarly analyzed.

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